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Revolutionizing Carbon Credit and Blockchain Solutions for Sustainability and Climate Stabilization

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Abstract

Climate change presents challenges that reach beyond mere environmental concerns. It is a key reality and needs to be highly sophisticated monitoring and control for carbon emissions. One of the most tantalizing areas is carbon credit markets that use blockchain technology. The traditional carbon credit accounting has been battling for years with the same setbacks: double counting of credits, tracking them across borders was too inefficient, verification took forever to be completely done and there were many fraudulent activities. These core weaknesses weaken the confidence in carbon markets and block advancements of climate action initiatives. This problem is solved by blockchain-based systems by having preserved immutably public ledgers of every transaction that takes place. This assigns each credit a unique identifier which can then be tracked and verified in real-time from issuance to ultimate retirement. This level of transparency minimizes avenues for manipulation while further cementing market integrity. We take a look at some major studies involving Blockchain that can enhance Carbon Credit works, boost acceptability of climate initiatives. It also digs in on case studies where blockchain has been deployed to track carbon credits, showing what sensical application looks like and the real-world benefits. At the same time, it faces huge challenges like energy consumption from blockchain operations, unclear regulation on carbon pricing to limit its adoption globally and integration with committed organizations using today's carbon accounting frameworks and protocols. The results underscore the critical importance of blockchain in ensuring climate accountability and protecting the integrity of carbon markets. This paper identifies key areas of research and development, offering insights into the future of carbon credit tracking and its potential impact on climate change through advanced technology.

Keywords

Carbon; Blockchain; Environment; Carbon credit; Climate change; Sustainability

Introduction

Climate change is one of the most urgent global challenges that faces us today, posing a higher risk to communities and economies as well as to natural ecosystems around the world. These extreme weather patterns, flash floods to prolonged droughts and the unexpected cloudburst only reinforce the urgency of sustainable development interventions (Halunko *et al*., 2024). The international community is no longer oblivious to the catastrophic consequences of human-induced climate change and the urgent need for explicating, analogical investigations of greenhouse gas emissions which are adding impetus to global warming (Opalchuk *et al*., 2024). Industries face mounting pressure to monitor and reduce their carbon footprints as part of worldwide efforts to limit emissions and promote sustainable futures. International organizations have responded to the climate crisis by introducing various measures, with carbon credits emerging as a crucial tool for greenhouse gas emission reductions. Landmark agreements, including the Kyoto Protocol and the Paris Agreement, have sparked global commitments to substantial emission reductions, establishing ambitious carbon neutrality targets for 2050. These conventions emphasize accurate carbon accounting's importance for emissions tracking while driving the establishment of regulations such as carbon taxes and industry-specific emissions standards. Through all these initiatives, the organizations worldwide increasingly commit to the supporting transitions toward sustainable, net-zero futures.

Within the last 20 years, there has been a global push to regulate these carbon emissions, culminating in the international community agreeing to combat climate change with efforts like the Paris Agreement. They formed carbon credit markets of which carbon dioxide emissions became tradable commodities within cap-and-trade systems (Oxford Entry Forum, 2022). Markets that motivate firms to either reduce their own emissions or invest in projects that promote sustainability. Stewardship intents to measures and quantifies greenhouse gas (GHG) emissions such as energy, transportation, with additional land use which are essential inputs for achieving your sustainability objectives and risking regulatory non-compliance. Carbon credits and offsets have become crucial to the emission reduction process (Ambily and Ulaganathan, 2024). The primary World Bank collection of development indicators, compiled from officially-recognized international sources, carbon credits are tradable units representing one ton of carbon dioxide (CO_2) that has either been avoided (via Clean Development Mechanisms and Joint Implementation), reduced, or removed from the atmosphere through a sustainable project. Such credits serve as hot properties in carbon markets, creating a way for industries to counterbalance their emissions. Since the 1997 Kyoto Protocol, carbon credits were introduced to encourage countries to reduce their emissions with any surplus sold in carbon markets. By market-based system, it means that a compliance and voluntary models; where, the compliance model is regulated one introduced by the authorities often compulsory with penalty for non-adherent whereas voluntary models are adopted by industries through there initiatives to be sustainable (Zhang, Chen and Yue, 2024). In both cases, carbon credits can be bought and sold by companies that either surpass or fall short of emissions targets, creating financial motivation for eco-friendly practices.

The Carbon Assets Tracking System (CATS) under the World Bank Programs supports emissions reduction tracking and transactions, helping industries adhere to climate goals (The World Bank, 2024). India's 2023 Carbon Credit Trading Scheme (CCTS)

established a national carbon market to cap emissions and promote sustainable practices, complemented by the Draft Green Credits which emphasizes tree planting, water conservation, and other ecological efforts (Government of India, 2024). Through these systems, companies and governments work toward carbon neutrality, supporting global climate goals and fostering a sustainable ecosystem (Bari, 2023).

Methodology

This research adopts a doctrinal legal research approach, aimed at understanding and critically examining the existing legal frameworks, institutional practices, and international developments related to carbon credit systems and blockchain technology in the context of sustainability and climate stabilization. The study follows a primarily desk-based approach, relying on careful reading and analysis of primary legal sources, including national laws, government regulations, international agreements, and judicial decisions. One of the main objectives was to identify the global legal commitments for carbon reduction and climate actions as documented in key international instruments (i.e. Kyoto protocol, Paris agreement, UNFCCC documents) The study relies on a wide range of secondary sources such as academic journal articles, policy papers, expert analyses, institutional reports and case studies. These materials were compiled from reliable sources, the World Bank, the European Commission, national governments, and environmental organizations with some focusing on carbon credit market working dynamics (where appropriate) or how blockchain is being implemented/exploration. A comparative section takes stock of country- or region-specific experience in terms to carbon trading and digital environmental governance innovations The beauty of a comparison like this is it also shows us the ways in which carbon credit systems are working and where development might be necessary. The research synthesizes across the literature on environmental policy, sustainability studies, and practical case examples to present a full picture of how legal systems affect climate outcomes. Rather than an abstract legal theory, the study looks to how laws work in practice and even barely touches what education is for. With this wider view in mind, we will seek to provide a set of practical proposals that could inform the development of future regulatory and policy landscapes for carbon credits and ethical national deployment plans for emergent technologies.

Challenges In Traditional Carbon Accounting

While carbon markets are a compelling concept, they still have issues relating to transparency, accuracy and scalability. These operations are prone to the lapses already discussed while relying on outdated methods of tracking. This can be a highly complex process due to the number of intermediaries that characteristically represent part of the chain of custody for a single carbon credit, along with differing record-keeping standards. These gaps make system distrustful and create problems for large scale implementation. Data integrity, ensure meeting data public availability not tempered with the problem is that many conventional carbon reporting systems do not provide the transparency needed for credibility, especially when much of the data collection and reporting methods used by companies are dated such as manual record-keeping, spreadsheets or self-reporting. Those traditional methods are limited in terms of time-spent and subject to erroneous input, whether intentional or not.

Transparency in carbon accounting is critical because it ensures emissions data are reliable and exposed to stakeholders, a group which includes governments, businesses, investors and the general public. Transparency is a key to stakeholder confidence. It is important for stakeholders to be able to check whether or not organizations are actually successful in achieving their emission reductions. Without transparent and consistent reporting, it is near impossible to hold actors accountable for their environmental performance (Merlo *et al*., 2025). Even in cases such as these, firms may intentionally underestimate their pollution levels or overstate achievements creating false impressions about sustainability. This disconnects between claims and reality erodes trust, which in turn slows global progress toward climate solutions.

Information asymmetry also supports greenwashing, where environmental claims are exaggerated or false. Additionally, the issue is further compounded as emissions data typically come from disparate sources and supply chains, which are too fragmented to be consolidated into accurate, one-size-fits-all pictures. In such a broken landscape, it becomes easier to massage data and harder to detect fraud (Boumaiza, 2024). Further complications come from the laborious nature of a lot of reporting systems, that have a slow and retrospective element to them. Companies are not able to prove accountability quickly and stakeholders cannot act fast when there is a sign of a problem. Orders of delays and errors slowly demolish the credibility to act from reinforcement (REJOLUT, 2024). Last, with carbon markets budding they will be incorporating projects from polar opposites of the globe – with unique environmental standards and processes. There is too much complexity to handle this scale using traditional systems (Hossain, Atibudhi and Mishra, 2023).

Another issue of credibility is double counting, often occurring in voluntary markets since the same carbon credit could be counted or claimed by many players. This lack of standardized follow-up questions the credited carbon reductions in these projects and renders voluntary markets hands-off in terms delivering to the efforts laid out respectively with the Paris Agreement or UN Sustainable Development Goals. Further, to foster credibility, carbon markets need to ensure that projects are real and delivering verifiable positive environmental outcomes as well accurate reporting but also establish coherent systems in line with Article 6 of the Paris Agreement. But globally reporting and verifying emissions reductions remains problematic due to the lack of coordinated guidance across registries.

Blockchain Technology: An Overview

Emerging digital technologies are crucial for establishing a unified data system that collects and organizes publicly available carbon credit information, thereby enhancing transparency, trust, and integrity. Among these technologies, blockchain stands out as a leading solution for improving transparency and traceability. Blockchain technology is founded on a decentralized and distributed ledger system where transactions are recorded in blocks linked in a chain (Boumaiza and Maher, 2024). Each block contains a list of transactions, a timestamp: and a cryptographic hash of the preceding block, ensuring that once added, it cannot be altered retroactively without consensus from the network. Unlike traditional databases controlled by a single entity, blockchain operates across a network of nodes, each maintaining a copy of the ledger. Transactions are visible to all

network participants, fostering trust and accountability. Cryptographic techniques secure data and ensure ledger integrity. Once data is recorded, altering it is nearly impossible, preventing fraud and tampering.

Each block is validated by a consensus algorithm, ensuring the integrity of the data. By leveraging blockchain technology, businesses can re-engineer their carbon supply chains and optimize carbon credit management, making them more environmentally responsible and compliant with emission regulations. Typically, businesses utilize private or consortium blockchains, where access is granted by a governing entity and transactions are validated accordingly (Ducas and Wilner, 2024). This structure fosters trust among participants, as each validated transaction is immutable and timestamped. In the event fraudulent activity, the blockchain's traceable records can pinpoint the source, which is particularly valuable in complex supply chains vulnerable to counterfeiting.

Smart contracts are what blockchain supports automated code pieces to make actions go off when certain criteria are reached. Smart contracts can keep track of the development of assets in supply chain, update records, enable automatic payments upon delivery and raise alerts to trigger manual intervention where necessary. This saves on administrative costs and is more secure than having human intervention. Internet of Things (IoT), devices are combined with smart sensors to connect scarce digital data and physical assets to keep track of the data useful for machinery and other transportation in supply chains, located energy efficiency is achieved outside.

Blockchain as a Solution for Carbon Credit Tracking

Supply chains are now more complex and fragmented than ever, which make it difficult to track carbon emissions with any meaningful accuracy. Old-school methods are often insufficient, providing a series of barriers that impede transparency and reliable data or get serious in the carbon asset management. Decentralized, tamper-proof systems enabled by blockchain technology provide an appealing mechanism to address these problems and boost supply chain-level transparency and accountability around carbon (Lozo and Onishchenko, 2021). Through the implementation and integration of blockchain within their carbon accounting systems, businesses can authoritatively gather, verify and even share data relating to emissions with stakeholders in a way that supports environmentally sustainable practices and comports with governmental regulations.

In blockchain technology, the distributed ledger enables any number of entities to securely track emissions from multiple sources while enabling green investments and data-based decision-making for sustainability. The World Bank’s International Finance Corporation (IFC) has already kicked off some blockchain-powered undertakings aimed at recording carbon removal interventions, as well as transforming carbon credits into crypto tokens to be utilized in a broader market (Mofatteh *et al*., 2024). These efforts show the promise of blockchain to open new pathways in carbon markets and catalyze collective action against global warming. By establishing calibrated ledgers across all lifecycle touch points, but enabling private, permissioned blockchain platforms for their specific needs per supply chain. Participation in these inter-linear systems turns individual points of interaction into systemic efforts to reduce the carbon footprint of final products, removing reliance on third-party carbon credit markets and provides

increased transparency between eco-spec related actors. Blockchain provides new methods to manage emissions data in far more efficient ways and promote trust between stakeholders. Here are primary ways blockchain enhances carbon accounting:

Real Time Data Collection and Monitoring with Blockchain and IoT Integration

By using IoT devices in combination with blockchain technology, a viable solution for keeping real-time data on carbon emissions is available. Blockchain allows automatic data recording, which is crucial for real-time reporting by extracting data from multiple sources. Hence, IoT devices can easily send data regarding energy usage, emissions among others to be recorded in blockchain ledgers that are truly transparent and not tamper proof.

Now more than ever, with complex supply chains changing constantly, businesses need this real-time monitoring in order to keep emissions data accurate and adaptable. Because blockchain records emission-related events such as logging or goods transport the moment they occur, the information is instantly accessible to any authorized stakeholders and can be analyzed and actioned on rapidly. Such agility is critical in detecting and thereby addressing any sudden increase in emissions to ensure that no violations occur with regulatory norms, and strong corrective action. Due to its real time updates with respected bodies, Blockchain provides current and up-to-date emission factors and environmental data for a more responsive carbon footprint calculation (Krishnan, Sahdev and Paul, 2024). When combined with IoT-driven data inputs, it dramatically increases the accuracy of carbon management and accountability across global supply chains.

Comprehensive Traceability

Carbon traceability largely remains a dark art given the difficulty in providing end-to-end visibility across supply chains and drawing lines from raw material sourcing to product distribution. Blockchain technology resolves this by creating a common, tamper-tolerant platform where emission data can be recorded and traced at each level (extraction/manufacturing/transport/market). Business can use this extensive report to visualize their sustainability impacts, meet carbon regulations & find emission hotspots for targeted reductions (Prapulla *et al*., 2024). In addition, the blockchain can provide an end-to-end supply chain life cycle analysis for carbon accounting as it be used to collect data from every part of the process.

Immutable Records: Ensuring Reliable and Tamper-Proof Carbon Data

Once the data is recorded on blockchain, it cannot be changed or removed (making it impossible to alter the emission data) and this ensures a Seamless and unchangeable record. This proves crucial for carbon traceability, reassuring stakeholders like suppliers, customers, regulators, and investors of the integrity of the data. In blockchain networks, emissions from fuel consumption or transportation could be data points that find themselves among individual blocks, connected by way of a cryptographic hash (Zhou, 2024). In order to change one block, then, you would have to change every single block after it on the blockchain without having anyone notice. Such transparency boasters the

confidence level on carbon data and increases the trust factor for sustainable development report, to justify the environmental impact claims being made.

Smart Contracts: Automating Carbon Compliance and Market Efficiency

Smart contracts are also poised to automate the terms of carbon accounting procedures as self-executing agreements coded onto blockchain systems. These digital contracts entitle those who have pledged to safeguard, maintain and retain emissions data exactly as it is specified but topographically in which the title holders are positioned. Smart contracts are an example that reducing the burden of manual interventions by enhancing data consistency, mitigating human error risks and streamline regulatory compliance leading to higher reliability & efficiency in environmental reporting (Opalchuk *et al*., 2024). More than just a way to drive up market liquidity, this automation has the knock-on effect of lowering barriers to entry and helping new types of projects develop and bring more flexible, inclusive carbon markets from the fringes.

Transparent Carbon Credit Tracking: Ensuring Integrity and Traceability

Through the blockchain technology, widely transparent and tamper resistant systems emerge for tracking carbon credits and offsets across their entire life-cycles. When credits get issued, blockchain records capture details about the generating project, the amount of emissions reduced, and the date of issuance. Trading activities add every transaction to the blockchain, building complete and unchangeable ownership histories. This level of transparency stops double counting and fraudulent activity (Kong, 2023), guaranteeing that each carbon credit stands as unique and accurately reflects actual emissions reductions. Blockchain strengthens carbon market integrity by creating verifiable paths from initial issuance through final retirement (Tsai, 2025).

Carbon Credit Tokenization

Democratizing access to carbon markets becomes possible through blockchain technology's approach to carbon credit tokenization. The tokenization process represents assets on digital ledgers, enabling companies that pursue carbon neutrality to work directly with suppliers (The World Bank, 2024). Community members gain the ability to buy, sell, or trade these credits through blockchain platforms, creating grassroots carbon offsetting approaches and supporting local environmental initiatives. Suppliers can offer carbon credits as Non-Fungible Tokens (NFTs), making the trading process simpler. Organizations receive robust frameworks for encouraging and rewarding sustainability efforts when blockchain creates tokens representing verified emissions reductions.

Accountability in Emissions Reporting

Public access to emissions data through blockchain strengthens both trust and accountability. Organizations that record carbon footprint information on public blockchain allow various stakeholders like customers, investors, and regulators to verify emissions data independently. This transparency encourages organizations to reduce emissions actively, understanding that their environmental impact remains visible to public examination.

Enhancing Stakeholder Trust and Engagement through Blockchain

The transparency and permanence built into blockchain technology significantly strengthen trust and engagement across stakeholder groups. When emissions data gets recorded securely, stakeholders can depend on its accuracy and tamper-resistant qualities, which matters greatly to investors and customers who want to support environmentally responsible organizations. Real-time monitoring of portfolio companies' environmental performance becomes possible for investors, encouraging accountability and forward-thinking climate action.

Corporate sustainability reporting sees major improvements through blockchain's contributions (Richardson and Xu, 2020). Companies can use blockchain platforms to document and verify greenhouse gas emissions and reduction efforts as they happen, building trust among stakeholders like investors, customers, and regulators. This transparent reporting mechanism is expected to help drive increased market valuation and enhance brand equity visibility, as well as provide a pathway for stakeholders to more effectively measure progress with respect of corporate sustainability targets and ESG (Environmental, Social and Governance) obligations. These smart contracts work to, in the end, place blockchain as a ground for secure and transparent collaborations on various aspects of sustainability among all players including suppliers, buyers or customers even regulatory bodies and opening ways out there too towards more collective sustainable initiatives/knowledge sharing etc.

Streamlining Regulatory Compliance with Blockchain Technology

Regulatory compliance becomes easily manageable when blockchain technology automates the emissions reporting and the verification procedures. Organizations can automatically gather and verify emissions data through smart contracts, maintaining regulatory standards without human involvement. Administrative workloads decrease and compliance efficiency improves through this automation. Regulators benefit from blockchain's transparent and unchangeable characteristics, which provide dependable data sources for effective monitoring and enforcement.

Addressing the intricate nature of carbon market regulatory compliance might involve creating blockchain-based "Compliance Ledgers." These ledgers would maintain detailed records of companies' carbon emissions, reduction activities, and credit transactions. Transparent and tamper-resistant records through Compliance Ledgers make reporting to regulatory agencies simpler, helping companies show compliance with local and international environmental rules more easily.

Enhancing Efficiency and Cost Savings

Carbon accounting implementations of blockchain technology can produce significant cost reductions and operational improvements. Automation of data collection, verification, and reporting processes through blockchain decreases the need for manual work and reduces error possibilities. Lower administrative and compliance expenses often result from this improved efficiency. Organizations can make better-informed

decisions about their emissions reduction approaches when blockchain data provides transparency and reliability, leading to more effective carbon management.

Streamlining Emission Reduction Verification

Emission reduction verification becomes automated when blockchain works together with smart contracts and Internet of Things (IoT) technology. IoT sensors monitoring CO_2 captured by carbon capture facilities can log this information directly onto blockchain systems. Smart contracts then issue carbon credits automatically based on confirmed emission reductions, making certification procedures smoother while reducing chances of human error or tampering. Blockchain technology's built-in transparency and traceability improve the ability to audit carbon footprint calculations. Stakeholders, including regulatory agencies and consumers, can feel more confident about reported emissions accuracy because they can follow each verification step.

Enhancing Renewable Energy Trading

Blockchain technology facilitates the creation of renewable energy trading platforms that enable direct interactions between clean energy producers and consumers. This direct engagement can boost both the demand and supply of renewable energy, while also opening up investment and financing opportunities for green projects (Basu, Deb and Singh, 2024). Blockchain supports the mobilization of climate finance from diverse sources, including governments, private sector entities, and individuals, thereby aiding the implementation of low-carbon solutions.

Case Studies of Blockchain Implementation in Carbon Credit Systems

IBM and Energy Blockchain Lab (China)

The techno giant IBM in collaboration with the Chinese government is creating a blockchain platform to fight against the carbon emission. IBM bags that it has designed first of its kind in the world, “green asset management platform” with an objective to decrease the carbon emissions and parallelly promoting technology that facilitates low carbon emissions. The blockchain based carbon management program is designed for businesses and is powered by the open-source Hyperledger Fabric. IBM and Energy Blockchain Labs, a Chinese business, collaborated to develop the solution. The development coincides with China's efforts to meet pre-2020 climate change action commitments (Zhang, Chen and Yue, 2024). The establishment of a uniform national carbon market is one of the goals of that action plan, which China signed as part of the Paris Agreement.

China, one of the biggest carbon dioxide polluters in the world, is under growing pressure to cut its greenhouse gas emissions and adapt to cleaner energy sources. To encourage businesses to lower their emissions, the nation responded by implementing a nationwide emissions trading system (ETS). Like in other places, China's conventional carbon credit system had problems with inefficiency, transparency, and verification. Carbon trading sometimes experienced delays and higher costs as a result of numerous middlemen and sophisticated certification procedures. With its proficiency in blockchain

technology, IBM partnered with Energy Blockchain Lab, a Chinese business that specializes in sustainable energy and environmental solutions. The objective of this collaboration is to utilize the inherent power of the blockchain technology which promotes transparency, security and traceability to transform the carbon markets.

IBM was in a highly dominant position to traverse the blockchain technology to the carbon credit system because of the reason that in recently explored blockchain for the banking sector and supply chain logistics industries. The energy blockchain lab and IBM collaborated to develop a blockchain-based platform specifically designed for managing carbon assets, including the entire lifecycle from credit creation to trading and withdrawal. To increase the market's efficiency and credibility, the platform was established with the goal of creating a standardized and secure digital ledger for carbon credit transactions. The partnership between IBM and Energy Blockchain Lab in China best exemplifies blockchain's transformational potential in carbon markets (Yadav *et al*., 2024). Blockchain addresses long-standing issues in carbon credit systems and establishes the framework for future environmental financing innovations by increasing transparency, efficiency, and integrity. This illustrates how science and technology affects sustainable development goals and is an essential move towards increasing the efficiency of global carbon markets in addressing climate change.

World Bank's Climate Warehouse Initiative

The World Bank's Climate Warehouse Initiative is another significant blockchain initiative, with the objective of improving the interoperability, transparency, and integrity of the world's carbon markets. The Climate Warehouse is an important step towards establishing a consistent, dependable system for handling emissions data beyond and across jurisdictions, addressing long-standing issues with cross-border monitoring and carbon credit credibility. By providing a decentralized registry for carbon credit data, the Climate Warehouse effort positions itself as a blockchain based platform that will facilitate enhanced transparency in global carbon markets by ensuring data integrity globally and integrating national carbon registries.

The application makes it easier to record and track carbon credits by connecting many national and regional registries. Blockchain is designed to ensure data integrity, preventing credits from being credited twice in different countries. To prevent credits from being counted or sold more than once, each carbon credit added to the Climate Warehouse is given a unique identifier. This is an essential factor as carbon credits can travel through multiple registers and jurisdictions, increasing the possibility of duplicate accounting (Samal and Samantaray, 2024). Carbon credits can also be audited in real time using the Climate Warehouse. Every ownership transfer and transaction are documented, resulting in an open record that auditors and authorities can analyses. This function eliminates fraud and promotes accountability among market participants. The World Bank's Climate Warehouse Initiative has demonstrated blockchain's game-changing potential in carbon markets, as it can overcome major obstacles such as double counting, fragmented regulations, and high entry fees by taking a decentralized, transparent approach. The Climate Warehouse would serve as the model as it grows bigger, for other sectors and institutions looking to enforce credible and effective carbon market monitoring.

Poseidon Foundation's "Reduce" Platform

The London based non-profit organization named Poseidon Foundation ("Poseidon") that created the world's first retail platform that connects customers with their carbon footprint. Poseidon's retail platform, which integrates carbon markets into point-of-sale transactions through blockchain technology which allows retailers and their consumers to support global forestry conservation initiatives when they buy and sell regular products, thereby contributing to climate change action. The Poseidon Foundation created the "Reduce" technology to integrate carbon markets into regular consumer transactions, allowing individuals and corporations to automatically offset their carbon footprint. Customers and businesses can include carbon credits in purchases using the Stellar blockchain. For example, a percentage of each transaction can be immediately allocated to the procurement of carbon credits, thereby offsetting the carbon footprint of that specific commodity or service.

The most notable features in the Reduce platform's is its inherent ability to fractionalize carbon credits. However, blockchain technology allows the platform to divide these credits into smaller bits, allowing customers to offset less carbon. Fractional credits enable consumers to minimize their carbon footprint on a micro level by allowing them to partially or completely offset everyday purchases such as a bus ticket or a cup of coffee. The Stellar blockchain enables the traceability of each carbon credit obtained through the Reduce platform. Users could see which project their carbon offset payment is going towards, whether it's a renewable energy project, a forestry project, or another permitted emission reduction endeavour (Naderi and Tian, 2022). Because the ledger offers a transparent record of every transaction, blockchain transparency guarantees that users can rely on the legitimacy of their offsets. Customers who want to make sure their contributions are actually making an impact are more likely to trust transparent businesses. The Reduce platform is integrated into point-of-sale systems by the Poseidon Foundation in partnership with a number of shops and companies. For instance, they collaborated with the London-based Ben & Jerry's ice cream shop to enable customers to instantly offset the carbon footprint of their ice cream purchases.

Veridium's Tokenized Carbon Credit Solution

Veridium's Tokenized Carbon Credit Solution is a ground-breaking application of blockchain technology that makes carbon credits more efficient, tradable, and available in the digital economy. IBM and Veridium a business that specializes in environmental solutions and sustainable development, collaborated to develop a blockchain platform that tokenizes carbon credits. Veridium hopes to simplify the carbon offset procedure, improve transparency, and boost market liquidity by converting conventional carbon credits into digital tokens. This will eventually make it easier for corporations to offset their carbon footprints (Erwin and Yang, 2023). Veridium's tokenised carbon credit system addresses a number of common concerns in the carbon market. Carbon credits, which are typically purchased by businesses to offset their greenhouse gas emissions, have been plagued by fraud, complexity, and transparency difficulties. Moreover, due to expensive transaction fees and middlemen, traditional carbon credits might be difficult to get, especially for smaller businesses. To overcome these issues, Veridium's

blockchain-based system converts carbon credits into digital tokens that are easier to buy, sell, and track.

Veridium built a network known for its efficiency, cheap prices, and scalability by leveraging IBM's blockchain technology knowledge. The platform attempts to help enterprises achieve their environmental goals by integrating with current carbon markets. This approach represents each carbon credit with a blockchain-based digital token. These tokens are created using verified carbon credits, such as those approved by the Verified Carbon Standard (VCS) or the Gold Standard. By acquiring these tokens, businesses or individuals essentially buy the right to offset a fixed amount of carbon emissions.

Veridium's digital platform makes it simple to purchase, sell, or trade tokens while maintaining a permanent document of each transaction. There are several advantages in tokenizing carbon credits. First, blockchain technology ensures that each token is unique, providing buyers and regulators with a clear audit trail. The blockchain records each token's origin, ownership history, and transaction data, reducing the likelihood of fraud and double counting. Furthermore, tokenization enables fractional ownership of carbon credits, or the capacity to divide credits into smaller units. Smaller firms who do not need or are unable to purchase a complete carbon credit but want to offset some of their emissions may benefit greatly from this alternative. The solution supports certified environmental projects such as reforestation and renewable energy by increasing the demand for verified carbon credits. When additional businesses purchase tokens to offset their emissions, a positive feedback loop of environmental impact is established, increasing the amount of money pouring into sustainability projects.

Veridium's tokenised carbon credit system represents an innovative application of blockchain technology in the carbon credit market. This initiative is addressing numerous traditional barriers to carbon offsetting, including transparency, accessibility, and confidence, by using blockchain technology to give visible, traceable, and liquid carbon credits (Song and Zhang, 2019). This platform not only helps businesses better regulate their carbon footprint, but it also directs more funding into approved environmental projects while supporting worldwide efforts to combat climate change. Veridium's concept exemplifies how technology may produce more impactful, efficient, and inclusive carbon markets as blockchain technology advances, thereby promoting global environmental and economic goals.

Moss. Earth: Tokenizing Amazon Rainforest Preservation

Moss. Earth, a Brazilian environmental technology company, was the first to advocate the use of blockchain technology to finance the preservation of the Amazon rainforest using tokenized carbon credits. The platform was created to help combat deforestation, one of the leading drivers of climate change, by making carbon credits easily accessible to businesses and individuals wishing to offset their carbon footprints. Moss. Earth encourages supporters to contribute to critical preservation efforts in one of the world's most important carbon sinks by tokenizing carbon credits linked with Amazon rainforest protection. The Amazon rainforest is known as the "lungs of the planet" because to its ability to absorb massive amounts of carbon dioxide from the atmosphere.

Moss. Earth identified an urgent need to conserve this valuable ecosystem and devised a blockchain-based solution that allows businesses and consumers throughout the world to support rainforest conservation by purchasing tokenized carbon credits (Vaccargiu and Tonelli, 2024). The platform was designed to make carbon offsetting easier to use and more transparent. Moss. Earth's use of blockchain technology not only allows for the financing of preservation, but it also provides clients with the assurance that their money is going directly to authorized environmental projects. Moss is responsible for issuing each MCO_2 token. Earth represents one ton of CO_2 offset by Amazonian rainforest conservation efforts. Carbon credits from proven conservation initiatives that adhere to strict environmental requirements, such as those approved by the Verified Carbon Standard (VCS), are utilized to create these tokens.

During the tokenization process, carbon credits are converted into a digital equivalent that can then be exchanged on Moss. Earth's platform (Abiodun, Nwulu and Olukanmi, 2024). MCO_2 token purchasers may connect their purchases to specific Amazonian conservation activities, ensuring that their money is supporting tangible and genuine results. The Moss. Earth platform's environmental and economic benefits extend beyond simply enabling carbon offsets. By giving funds to Amazon preservation, project helps to ensure the survival of rainforest ecosystems, protects indigenous populations, and conserves biodiversity. The Amazon rainforest is critical to maintaining the planet's climate, and Moss Earth supports global efforts to cut greenhouse gas emissions and prevent climate change by halting deforestation.

In terms of financing, Moss. Earth's platform provides Amazonian conservation organizations with a consistent flow of revenue, allowing them to continue functioning and developing. This support allows projects to recruit local labourers, purchase necessary equipment, and cover running costs, all of which benefit the local economy. This model exemplifies how blockchain technology might be utilized for environmental conservation by tokenizing carbon credits for the protection of the Amazon rainforest. Moss. Earth has established a transparent, easily accessible, and dependable carbon offsetting framework by tokenizing carbon credits associated with verified conservation initiatives, as well as assisting individuals and businesses in reducing their carbon footprint by providing critical funding for one of the world's most important ecosystems.

Challenges and Limitations of Blockchain in Carbon Accounting

Blockchain technology's potential to improve data quality, accountability, and transparency has led to its promotion as a game-changing tool for carbon accounting. Despite these benefits, blockchain implementations in carbon trading and accounting confront significant challenges that limit their effectiveness and scalability. The following sections address some of the major issues and limitations of blockchain in carbon accounting.

Scalability Issues

Scalability is a big issue for blockchain in carbon accounting. As the volume of carbon credit transactions increases, blockchain networks may slow down and become less effective. This causes a significant challenge for handling the enormous transaction

volume, which is frequent in carbon trading markets. Blockchain networks broadcast transactions over a dispersed network of nodes, each of which is responsible for recording and verifying the transaction. The network may get congested as transaction volumes increase, which could result in delays and increased transaction costs. If the network is unable to manage the high transaction throughput (number of transactions per second) necessary for real-time market operations, this scalability issue may jeopardize the technology's ability to serve substantial carbon trading markets.

Traditional blockchain networks, such as Ethereum and Bitcoin, rely on resource-intensive consensus techniques like proof-of-work (POW) and, more recently, proof-of-stake, which limits their ability to handle transactions. Congestion and expensive transaction fees may result from the volume of transactions that must be handled as carbon markets and emissions trading gain popularity. Platforms for carbon accounting must handle transactions quickly, particularly in international marketplaces where real-time data is crucial (Li, Liu and Rui, 2023). Although off-chain transactions and other scaling methods have been suggested, frilly scalable blockchain networks that preserve decentralization and efficiency are still being developed. This restriction results in delays and higher expenses for carbon accounting, which can compromise the efficacy of blockchain-based solutions.

Technical Complexity and Integration Challenges

The technical complexity of blockchain technology and its integration with current systems provide major obstacles to its application m carbon accounting. The architecture of blockchains can be quite complicated, especially in permissionless networks, and requires specific expertise to develop, implement, and maintain. Many find this complexity to be a hurdle, particularly NGOs or smaller businesses with fewer technical resources (Zhao and Peng, 2024). Furthermore, it can be difficult to integrate blockchain with conventional carbon accounting systems, which frequently make use of outdated databases or software. Without significant re-engineering, it may be impossible to integrate these historical systems seamlessly because they are incompatible with blockchain protocols.

Companies and interested m carbon accounting face a barrier to entry as implementing and administering blockchain technology necessitates a high level of technical competence. Because blockchain is Inherently complicated, deployment errors and inefficiencies may occur, making it more difficult to collect emissions data accurately and consistently. Many carbon accounting participants, particularly smaller businesses, might not have the funds or know- how to implement blockchain-based solutions. In addition to complicating user interactions, its Intricacy may prevent non-specialist users from using the technology and lower acceptance rates. Developers are attempting to solve this by making blockchain for carbon accounting applications simpler through the creation of more approachable user interfaces and instructional materials. However, the intricacies of blockchain will continue to impede its general use in carbon accounting in the absence of standardized protocols. Companies that are eager to use carbon accounting but lack the funds to change their systems may be discouraged by the high costs and potential delays caused by the requirement for significant technical adaptation.

High Costs and Energy Consumption

One of the biggest issues in terms of climate change mitigation is that blockchain networks are renowned for their high energy consumption. expenses, especially when they employ proof-of-work (POW) consensus processes, have been a challenge for many potential users. In high-volume carbon trading platforms, these expenses are frequently transferred to users in the form of transaction fees, which might be prohibitive (Baklaga, 2024). For instance, the sustainability of systems based on energy-intensive blockchains, such as Ethereum, has been weakened by significant transaction fees and environmental effects. These restrictions were encountered by Singapore-based Choon Energy when it used Ethereum for its carbon credit trading platform, where energy expenses and transaction fees drastically decreased platform usage. In addition to discouraging market participation, such exorbitant prices and energy requirements also Increase the carbon footprint, which runs counter to the environmental objectives of carbon trading.

Concerns about blockchain's applicability for carbon accounting, which by its very nature seeks to assist environmental goals, are raised by the high energy requirements for transaction validation on PoW-based blockchains. In order to protect transactions, blockchain networks like Bitcoin and pre Ethereum 2.0 use a lot of energy, which results in a significant carbon footprint (Kong, 2023). The environmental goals of carbon accounting and carbon credit trading are at odds with this energy need. While some networks have moved to energy-efficient consensus methods such as POS, there is still a need for long-term blockchain solutions that meet carbon accounting aims. The blockchain ecosystem must continue to explore at greener options to ensure that the technology's use in carbon accounting does not increase carbon emissions.

Transaction Delays

The probability of transaction delays is another disadvantage of blockchain technology in carbon trading markets. Every node in a distributed network that processes blockchain transactions confirms them. However, due to the lengthy procedure, there may be delays in transaction confirmation, especially during periods of high demand. For example, because blockchain networks have limited throughput, Verra, a corporation that sets standards for carbon credits, encountered transaction backlogs when using blockchain for carbon credit tracking. These delays have a significant influence on the efficiency and liquidity of the carbon trading markets, because rapid transaction processing is critical to the market's efficient operation.

The ability of diverse blockchain networks to connect and communicate with one another, known as interoperability, remains a significant barrier to carbon accounting applications. Blockchain systems vary greatly, each having its own set of standards, guidelines, and structures for governance. Participants in carbon accounting may need to use many platforms and cryptocurrencies, which can lead to inefficiencies, higher operational costs, and more complicated procedures. The idea of smooth data sharing and cross-platform carbon credit trading could be limited by a lack of interoperability, which might hinder cooperation between different carbon markets.

High Learning Curve and Limited Participation

The technological sophistication of blockchain technology may result in a high learning curve for carbon market participants. Active participation needs knowledge of blockchain issues like as smart contracts, decentralized finance (DeFi), and security protocols, which require significant time and expertise to master. Because they lack the funds to hire specialized workers or learn the necessary knowledge internally, smaller businesses and individuals may be discouraged from participating in blockchain-based carbon markets due to their complexity. The stringent participation restrictions of Klima DAO, a decentralized autonomous organization dedicated to carbon markets, for example, may prevent greater market participation and limit the inclusivity of blockchain-based carbon trading.

Regulatory Uncertainty and Legal Challenges

The regulatory framework within which blockchain technology operates is continuously evolving, particularly in terms of environmental applications. There is often little or no information on how blockchain-based carbon credits should be managed, and the legal framework for carbon credits varies widely between countries (Alzoubi and Mishra, 2023). This regulatory ambiguity may raise legal concerns, such as whether blockchain carbon credits are acknowledged by national and international carbon markets, or how well they comply with UNFCCC and other standards. Furthermore, jurisdictional issues exist in cross-border blockchain-based carbon trading because different countries' laws regulate carbon credits and blockchain transactions. The regulatory situation for blockchain in carbon accounting is largely uncertain. Regulations in the carbon trading business were designed prior to blockchain and may not be compatible with the new technology's features. Because firms and developers are unsure of how to comply with local, national, and international laws, regulatory uncertainty impedes the adoption of blockchain technology. Updating regulatory frameworks for blockchain requires time, teamwork, and government support. The legal issues surrounding the ownership, transfer, and international trading of blockchain-based carbon credits may also restrict blockchain adoption in carbon accounting.

Future Perspectives on Blockchain and Carbon Credit Tracking

Transparent, productive, and reliable carbon credit tracking systems are more critical than ever as climate change becomes an increasingly significant issue. Because of its decentralized, transparent, and permanent nature, blockchain technology has the potential to transform the carbon credit market. By exploring future perspectives on these technologies, we may learn more about how blockchain and carbon credit monitoring could disrupt the market, increase regulatory compliance, and boost international cooperation in the fight against climate change.

Enhanced Transparency and Trust

Blockchain could potentially serve as the base for open carbon credit monitoring systems, boosting confidence in international markets. Data tampering, double-counting, and opacity have plagued the carbon credit markets, undermining their

credibility and discouraging participation. Every transaction is recorded in the unchangeable ledger of the blockchain, which makes it possible to trace each carbon credit from issue until retirement (Mulligan, Morsfield and Cheikosman, 2024). All parties involved, governments, corporations, Investors, and environmental groups can instantly confirm the provenance, ownership, and status of carbon credits thanks to this transparency. As the market develops, transparency made possible by blockchain technology may lessen false claims and improve accountability, drawing in more players and increasing the legitimacy of carbon credit schemes.

Increased Regulatory Alignment and Compliance

Blockchain can assist m ensuring regulatory alignment across jurisdictions as global standards for carbon credits continue to develop. Global carbon credit markets are growing but there are inconsistencies in laws and regulations that can lead to uncertainty and contradictions. Blockchain's decentralized structure can help to provide a uniform, standardized system for tracking carbon credits, providing authorities with a reliable, real-time tool for compliance monitoring. Blockchain might automate verification of compliance by adding smart contracts, ensuring that credits meet specific regulatory standards before trading or retirement. This feature can assist firms in meeting global environmental standards by streamlining regulatory monitoring, minimizing compliance costs, and simplifying the auditing process.

Lowering Barriers for Small and Medium-Sized Enterprises (SMEs)

One positive feature of carbon credit tracking is blockchain's promise to democratize the market by eliminating barriers for small and medium-sized businesses. Traditional carbon credit markets may be out of reach for smaller enterprises due to expensive pricing, complex restrictions, and administrative constraints (Parhamfar, Sadeghkhani and Adeli, 2024). SMEs may be able to participate in carbon offsetting without needing to purchase complete credits due to blockchain's ability to fractionalize carbon credits, dividing them into smaller, more manageable units. Blockchain technologies may also make it easier for SMEs to buy, swap, or sell fractional credits, allowing them to offset their carbon footprint on a scale that suits their budget. This inclusion may increase participation in carbon markets and boost worldwide efforts to cut emissions.

Streamlined Market Operations with Smart Contracts

Carbon credit trades could be simplified and improved by using smart contracts, which are programmable protocols on blockchain networks. Transactions using carbon credits have normally entailed several middlemen, lengthy paperwork, and rigorous verification procedures, resulting in delays and increased costs. Smart contracts, by putting terms and conditions directly into the blockchain, have the potential to automate these processes. For example, a smart contract can promptly send funds to a seller after a carbon credit has been validated, transferred, and retired in accordance with established rules (Sipthorpe *et al.*, 2022). This technology has the potential to boost market liquidity for carbon credits by cutting transaction costs, reducing human error, and speeding up trading, making it easier for smaller enterprises to enter.

Global Collaboration and Cross-Border Carbon Markets

The capacity of the Blockchain's interoperability would be helpful in creating cross-border carbon markets, promoting international collaboration in climate action. Carbon credits from different national and regional markets may be sold on a worldwide scale as blockchain networks become more interoperable, allowing for smooth communication and data sharing between blockchains. This approach would create a single, worldwide carbon credit market, allowing states and organizations to trade transparently and consistently across national borders. Blockchain, by providing a secure record of transactions, has the potential to facilitate cross-border agreements and international cooperation on carbon reduction projects. A globally interoperable blockchain technology could someday help to build a single carbon market that optimizes global emissions reduction.

Sustainable Blockchain Innovations to Align with Environmental Goals

Blockchain's role in carbon credit tracking is expected to evolve towards more sustainable technology as worries about the energy usage of blockchain networks increase. Blockchain may become more compatible with the objectives of carbon markets if energy-efficient consensus techniques like proof of-stake (ROS) and proof-of-authority) are developed. Some blockchain initiatives show how lowering energy consumption can make blockchain a more practical tool for tracking carbon credits, such as Ethereum's transition to POS with Ethereum 2.0.

Conclusion

Blockchain technology has significant potential to transform carbon credit tracking towards a sustainable future by improving accountability, efficiency, and transparency in international carbon markets. However, achieving these potentials calls for a global effort that includes regulatory assistance, technological developments, and cooperation from all sectors. As previously mentioned, blockchain helps with many carbon accounting issues, such as enhancing data accuracy and decreasing fraud, but it also has major drawbacks, like scalability, unclear regulations, and energy usage. Therefore, measures that overcome these constraints and promote the sustainable expansion of carbon markets should be given priority in the future. The development of scalable, energy-efficient blockchain networks is a high objective for carbon credit tracking. Alternative consensus methods, such as proof-of-stake or proof-of-authority, that consume less energy and are better suited to the environmental goals of carbon markets, should be the primary focus of research and innovation. Blockchain technology would be better to satisfy the real-time requirements of carbon markets with further advancements in scalability and energy efficiency.

Regulatory concerns must also be addressed. To create a legal framework for blockchain-based carbon credits, states and international organizations must develop clear, consistent standards. In addition to enabling cross-border carbon trading, harmonizing regulations across jurisdictions helps ensure adherence to global agreements such as the Paris Agreement. In addition to boosting the credibility of blockchain-based carbon credits, creating a unified legal framework would stimulate

their widespread use. Governments, environmental groups, and techno giants blockchain developers can work together to create these standards, which will increase the technology's dependability and acceptance. Also, the establishment of a cohesive carbon market ecosystem is dependent on the promotion of interoperability among blockchain networks. Interoperability would simplify operations and enable more effective carbon credit trading by allowing for seamless communication across various blockchain platforms. To establish a global, unified carbon market and enable seamless data exchange across blockchain networks, efforts should be focused on defining interoperable standards for carbon accounting data. Likewise, this would make it easier for smaller players, such as small and medium-sized firms (SMEs), to participate in carbon offsetting.

Educating corporations and the general public about blockchain technology and its use in carbon accounting is another critical component of the future. Lowering the learning curve and boosting accessibility to blockchain technology can lead to a more inclusive approach to climate action and carbon market development. Developing educational materials and user-friendly interfaces will help stakeholders understand blockchain and interact with the technology with confidence. Finally, by providing security, openness, and accountability, blockchain technology has the potential to totally alter carbon credit tracking. Blockchain has the potential to be a critical tool in the battle against climate change if focused efforts are made to overcome concerns of scalability, energy consumption, legislation, and interoperability.

References

Abiodun, T.P., Nwulu, N. and Olukanmi, P. (2024). Application of blockchain technology in carbon trading market: A systematic review. *IEEE Access*, 1: 1–1. DOI: https://doi.org/10.1109/access.2024.3523672.

Alzoubi, Y.I. and Mishra, A. (2023). Green blockchain – A move towards sustainability. *Journal of Cleaner Production*, 430: 139541. DOI: https://doi.org/10.1016/j.jclepro.2023.139541.

Ambily, K.K. and Ulaganathan, A. (2024). Assessing Ecosystem Level Carbon Loss and Mitigating Capacity of Rubber (*Hevea brasiliensis*) Plantations in Hilly Regions in India. *Grassroots Journal of Natural Resources*, 7(2): 288-300. DOI: https://doi.org/10.33002/nr2581.6853.070215.

Baklaga, L. (2024). Synergizing AI and blockchain: Innovations in decentralized carbon markets for emission reduction through intelligent carbon credit trading. *Journal of Computer Science and Technology Studies*, 6(2): 111–120. DOI: https://doi.org/10.32996/jcsts.2024.6.2.13.

Bari, M. (2023). Carbon Credits Trading Scheme (2023): A greener future. Impact and Policy Research Institute. Available online at: https://tinyurl.com/22m7exmt [accessed on 5 June 2025].

Basu, P., Deb, P. and Singh, A. (2024). Blockchain and the carbon credit ecosystem: sustainable management of the supply chain. *Journal of Business Strategy*, 45(1): 33-40. DOI: https://doi.org/10.1108/JBS-09-2022-0157.

Boumaiza, A. and Maher, K. (2024). Leveraging blockchain technology to enhance transparency and efficiency in carbon trading markets. *International Journal of*

Electrical Power & Energy Systems, 162: 110225. DOI: https://doi.org/10.1016/j.ijepes.2024.110225.

Boumaiza, A. (2024). A blockchain-centric P2P trading framework incorporating carbon and energy trades. *Energy Strategy Reviews*, 54: 101189. DOI: https://doi.org/10.1016/j.esr.2024.101466.

Ducas, E. and Wilner, A. (2024). The security and financial implications of blockchain technologies. *JSTOR*, 4 November. Available online at: https://www.jstor.org/stable/26414135 [accessed on 5 June 2025].

Erwin, T. and Yang, B. (2023). Green energy, emissions, and blockchain technology. Cham: Palgrave Macmillan, pp.29–51. DOI: https://doi.org/10.1007/978-3-031-40647-8_3.

Government of India (2024). Carbon Market. Bureau of Energy Efficiency, 5 November. Available online at: https://beeindia.gov.in/en/programmes/carbon-market [accessed on 5 June 2025].

Halunko, V., Dolynska, O., Smyrnov, I., Horiunova, K. and Flinta, N. (2024). Political and Legal Framework for the Formation of Effective Strategies for Managing Sustainable Development in a Geographical Context. *Grassroots Journal of Natural Resources*, 7(3): s230-s252. DOI: https://doi.org/10.33002/nr2581.6853.0703ukr12.

Hossain, S.M., Atibudhi, H. and Mishra, S. (2023). Agricultural Vulnerability to Climate Change: A Critical Review of Evolving Assessment Approaches. *Grassroots Journal of Natural Resources*, 6(1): 141-165. DOI: https://doi.org/10.33002/nr2581.6853.060107.

Kong, E. (2023). How blockchain technology addresses the double counting of carbon emissions. Climate Action Data Trust, 29 November. Available online at: https://tinyurl.com/4u6ta7we [accessed on 5 May 2025].

Krishnan, C., Sahdev, S.L. and Paul, G.W. (2024). Blockchain-based traceability solutions for environmental sustainability. London: Routledge, pp.207–228. DOI: https://doi.org/10.4324/9781003378341-18.

Li, W., Liu, J. and Rui, J. (2023). Development of the carbon trading market empowered by blockchain characteristics. *Advances in Economics, Management and Political Sciences,* 50: 115-121. DOI: https://doi.org/10.54254/2754-1169/50/20230562.

Lozo, O. and Onishchenko, O. (2021). The Potential Role of the Artificial Intelligence in Combating Climate Change and Natural Resources Management: Political, Legal and Ethical Challenges. *Grassroots Journal of Natural Resources*, 4(3): 111-131. DOI: https://doi.org/10.33002/nr2581.6853.040310.

Merlo, A.L.C., Mendonça, D.S., Santos, J., Carvalho, S.T., Guerra, R. and Brandao, D. (2025). Blockchain for the carbon market: a literature review. *Discover Environment*, 3(68). DOI: https://doi.org/10.1007/s44274-025-00260-4.

Mofatteh, M.Y., Davallou, R., Ishimwe, C.N., Divekar, S.S. and Valilai, O.F. (2024). Developing a blockchain-based supply chain CO_2 footprint tracking framework enabled by IoT. *International Journal of Advanced Computer Science and Applications*, 15(10). DOI: https://doi.org/10.14569/ijacsa.2024.0151002.

Mulligan, C., Morsfield, S. and Cheikosman, E. (2024). Blockchain for sustainability: A systematic literature review for policy impact. *Telecommunications Policy*, 48(2): 102676. DOI: https://doi.org/10.1016/j.telpol.2023.102676.

Naderi, N. and Tian, Y. (2022). Leveraging blockchain technology and tokenizing green assets to fill the green finance gap. *Energy Research Letters*, 3(3). DOI: https://doi.org/10.46557/001c.33907.

Opalchuk, R., Shepel, A., Dimov, I., Andrushko, R. and Andrushko, M. (2024). Ensuring Sustainable Development of the Agricultural Sector through Financial Instruments in the Context of Climate Change. *Grassroots Journal of Natural Resources*, 7(3): s349-s377. DOI: https://doi.org/10.33002/nr2581.6853.0703ukr18.

Oxford Entry Forum (2022). The Evolution of Carbon Markets and Their Role in Climate Mitigation and Sustainable Development. The Oxford Institute for Energy Studies, June. Available online at: https://tinyurl.com/7n2hf97m [accessed on 5 June 2025].

Parhamfar, M., Sadeghkhani, I. and Adeli, A.M. (2024). Towards the net zero carbon future: A review of blockchain-enabled peer-to-peer carbon trading. *Energy Science & Engineering*, 12(3): 1242-1264. DOI: https://doi.org/10.1002/ese3.1697.

Prapulla, S.B., Hamsaveni, R., Himashree, N.R., Madhubala, M., Lavanya, M., Sata, A. and Patra, S. (2024). Blockchain-powered carbon credit management: Innovating sustainability tracking. *IEEE Xplore*, 1–7. DOI: https://doi.org/10.1109/csitss64042.2024.10817037.

REJOLUT (n.d.). Blockchain-based carbon credit ecosystem. Available online at: https://www.rejolut.com [accessed on 15 May 2025].

Richardson, A. and Xu, J. (2020). *Carbon trading with blockchain*. Cham: Springer,. pp.105–124. DOI: https://doi.org/10.1007/978-3-030-53356-4_7.

Samal, P. and Samantaray, S. (2024). *Blockchain technology as a tool for mitigating environmental sustainability in supply chain networks*. Springer International Publishing, pp.597–611. DOI: https://doi.org/10.1007/978-981-99-8628-6_50.

Sipthorpe, A., Brink, S., Leeuwen, T.V. and Staffell, I. (2022). Blockchain solutions for carbon markets are nearing maturity. *One Earth*, 5(7): 779–791. DOI: https://doi.org/10.1016/j.oneear.2022.06.004.

Song, Z. and Zhang, G. (2019). Environmental monitoring data storage system based on consortium blockchains. *IEEE Xplore*. DOI: https://doi.org/10.1109/ICIIBMS46890.2019.8991539.

The World Bank (2024). Carbon Assets Tracking System. IBRD – IDA, 5 November. Available online at: https://cats.worldbank.org/ [accessed on 6 May 2025].

Tsai, Y. (2025). Enhancing transparency and fraud detection in carbon credit markets through blockchain-based visualization techniques. *Electronics*, 14(1): 157. DOI: https://doi.org/10.3390/electronics14010157.

Vaccargiu, M. and Tonelli, R. (2024). Blockchain projects in environmental sector: Theoretical and practical analysis. *Earth*, 5(3): 354–370. DOI: https://doi.org/10.3390/earth5030020.

Yadav, A., Shivani, S., Manda, V.K., Sangwan, V. and Demkiv, A. (2024). Blockchain technology for ecological and environmental applications. *Ecological Questions*, 35(4): 1–20. DOI: https://doi.org/10.12775/eq.2024.050.

Zhang, G., Chen, S.C.I. and Yue, X. (2024). Blockchain technology in carbon trading markets: impacts, benefits, and challenges—A case study of the Shanghai Environment and Energy Exchange. *Energies*, 17(13): 3296. DOI: https://doi.org/10.3390/en17133296.

Zhang, G., Chen, S.C-I. and Yue, X. (2024). Blockchain Technology in Carbon Trading Markets. *Energies,*17 (3): 3299. DOI: https://doi.org/10.3390/en17133296.

Zhao, Y. and Peng, Y. (2024). Innovation and improvement of carbon emission trading management model under blockchain technology. *IEEE Xplore*, 91–95. DOI: https://doi.org/10.1109/icdacai65086.2024.00024.

Zhou, W. (2024) Optimized application and potential impact of blockchain technology in carbon trading. *Finance & Economics*, 1(1): 5. DOI: https://doi.org/10.61173/7p5cjg77.

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Authors' Declarations and Essential Ethical Compliances

Authors' Contributions (in accordance with ICMJE criteria for authorship)

Contribution	*Author 1*	*Author 2*	*Author 3*
Conceived and designed the research or analysis	Yes	No	Yes
Collected the data	No	No	Yes
Contributed to data analysis and interpretation	Yes	Yes	No
Wrote the article/paper	Yes	Yes	No
Critical revision of the article/paper	No	Yes	No
Editing of the article/paper	No	Yes	Yes
Supervision	No	No	Yes
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